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Relationships between lower-limb joint kinetics during the support phases of sprint running and rebound jumping

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Introduction

Sprint running (sprinting) is critical to performance in many sports. To improve sprint performance, it is necessary to increase the mechanical output of lower-limb muscles during the support phase, as it is the only phase in which the entire body undergoes acceleration and deceleration. Plyometric training using jump exercises can increase mechanical output in sprinting. Many studies have investigated the relationship between sprint performance and the performance of various jumps, including vertical jumps (countermovement jump, drop jump, and rebound jump) and horizontal jumps (bounding)^{4,8,10,11}. Due to the significant correlation between sprinting and jumping abilities, most types of jumping are important for sprinting, and so these jumps are also useful training exercises for improving sprint performance. However, the relationship between the performance of sprinting and the performance of bounce-type or rebound-type double-leg jumping in the vertical direction (jumping as high as possible with minimum ground contact time, as shown in rebound jumping) remains unclear. The few studies investigating this relationship have shown no correlation, suggesting that the performance of rebound jumping may not be important for sprinting^{10,11}. The benefits of plyometric training are influenced by the induced joint torque and power of the plyometric exercise. Therefore, it is important to understand the relationship between both the performance variables and the joint kinetics in sprinting and jumping exercises.

The purpose of this study was to investigate the relationship between lower-limb joint kinetics during the support phase of sprinting and rebound jumping.

Methods

Subjects

Sixteen male track and field sprinters and jumpers (age, 22.19 ± 1.11 years; height, 1.76 ± 0.05 m; and mass, 67.32 ± 5.06 kg) performed sprinting and rebound jumping at maximal effort. The Ethics Committee for the Institute of Health and Sport Sciences, University of Tsukuba, Japan approved all study procedures.

Procedures

After warm-up, participants performed maximum-velocity sprinting and rebound jumping at least twice. Participants were videotaped in the sagittal plane with a high-speed video camera (EX-F1, 300 fps; Casio, Tokyo, Japan). Ground reaction force was obtained from force platforms (9287B $0.9 \text{ m} \times 0.6 \text{ m}$; Kistler Instrumente AG, Winterthur, Switzerland; 1,000 Hz).

The rebound jump test consisted of five repeated rebound-type jumps in the vertical direction with a double-leg takeoff from a standing position. Participants were orally instructed to jump as high as possible and to minimize ground contact time. For sprinting, all participants performed 60-m sprints, consisting of a 30-m build-up followed by a timed “flying 30 m” over the force plate.

Data analysis

In total, 23 body points and four calibration markers were digitized using a Frame-DIAS system (DKH Co., Tokyo, Japan), starting from 10 frames prior to touch-down and ending at 10 frames after toe-off. The coordinates were smoothed by a Butterworth digital filter with optimal cut-off frequencies of 7.5–10.5 Hz, determined using the residual method¹³.

In sprinting, horizontal velocity, step length, and

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frequency of a single step were calculated. The RJ index for rebound jumping was calculated by dividing jump height by contact time^{11,15)}.

During sprinting and rebound jumping, the location of the center of mass and inertia of each segment were estimated based on the body segment parameters by Ae¹⁾. Joint torques were calculated using an inverse dynamics approach. Joint power was calculated as the dot product of joint torque and angular velocity. Extension and plantar flexion were denoted as positive at each of the three leg joints.

Statistical Analyses

The Pearson's correlation coefficient was used to determine the relationships between variables during sprinting and rebound jumping. Statistical significance was set at $P < 0.05$.

Results

There was no significant correlation between sprint velocity and RJ index (Fig. 1).

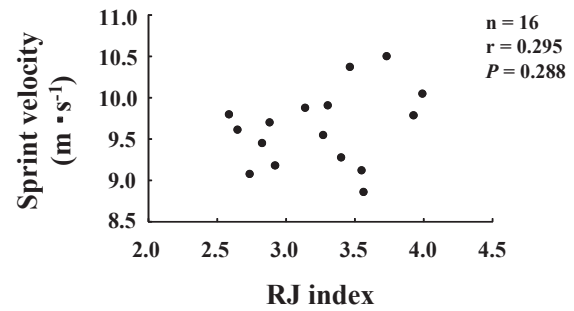


Fig. 1 Relationship between the sprint velocity and the RJ index.

In Figs. 2 and 3, the mean joint torque and power values of the ankle, knee, and hip during sprinting are plotted against those for rebound jumping. For mean joint torque, a significant correlation between sprinting and rebound jumping was noted for the ankle and knee joints in both the eccentric and concentric phases. For mean joint power, significant correlations between sprinting and rebound jumping were observed for the mean negative power of both the ankle and knee joints.

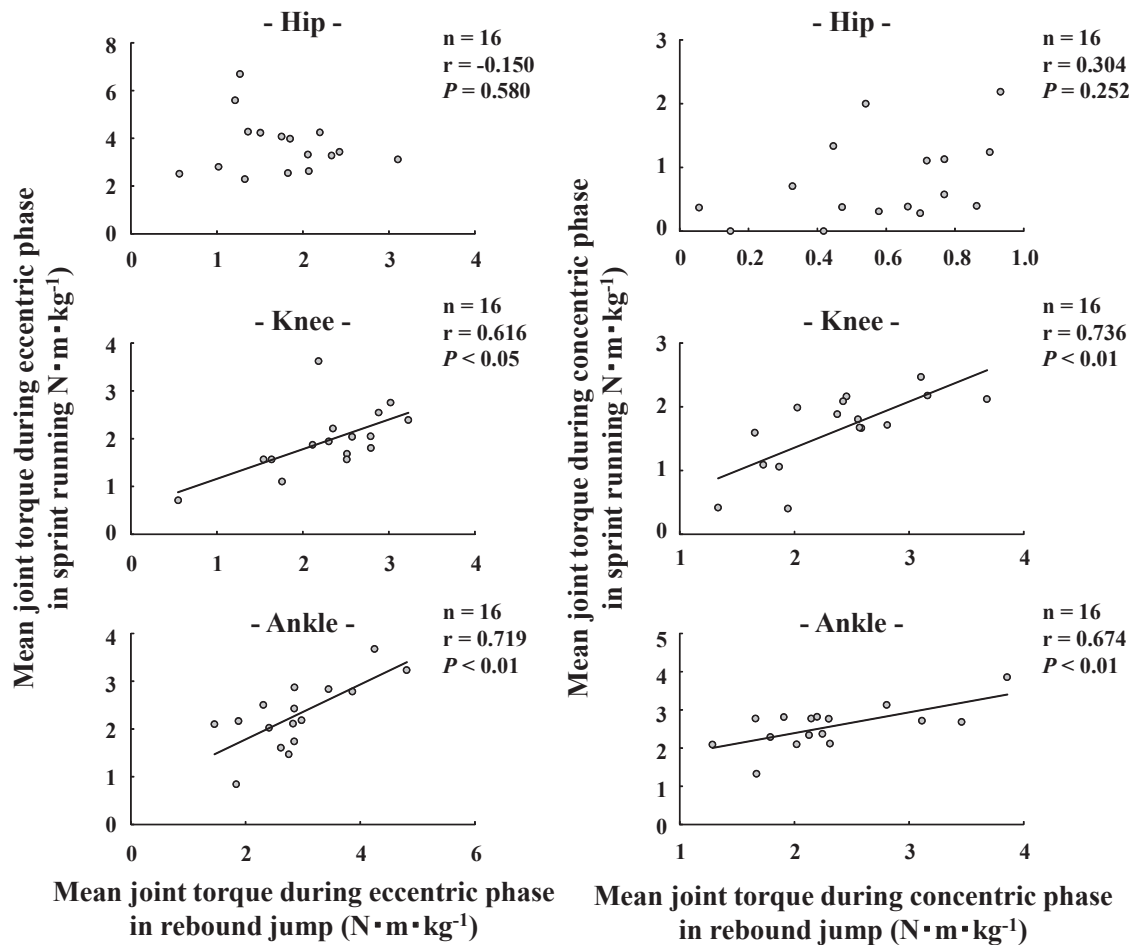


Fig. 2 Relationships between sprint running and rebound jump for the mean joint torque during the eccentric and concentric phases.

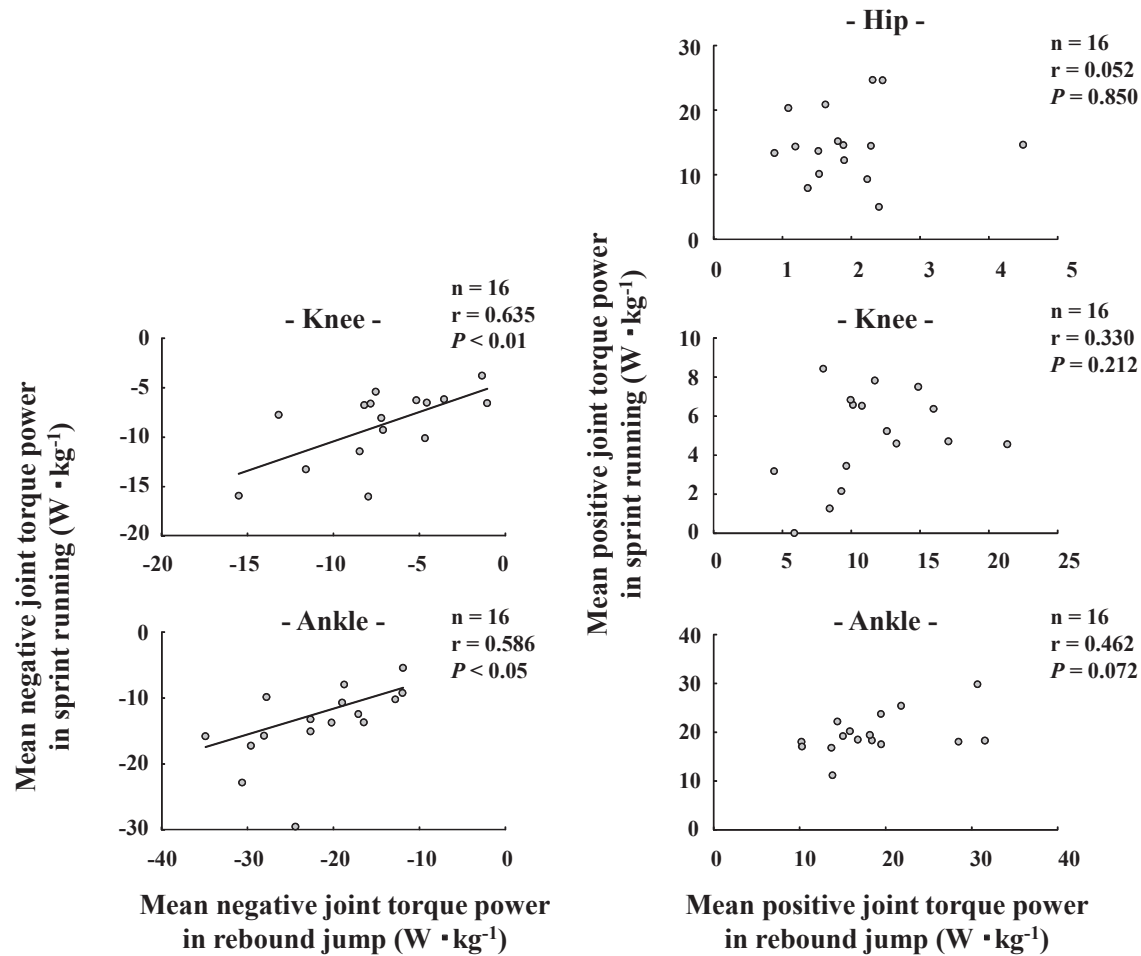


Fig. 3 Relationships between sprint running and rebound jump for the mean negative and positive joint torque powers.

Discussion

During sprinting, the ankle joint plays an important role in achieving high performance by producing a large vertical force⁵, and enhancing mechanical efficiency⁹, indicating that the ankle joint is important for sprinting performance. In rebound jumping, performance is known to be primarily affected by the ankle joint¹⁴. Moreover, ankle-joint functions important for sprinting (enhancing mechanical efficiency and reducing ground contact time) are also important for rebound jumping¹⁴. Collectively, these results explain the significant relationship observed between ankle joint kinetics during sprinting and rebound jumping.

Additionally, a correlation was also noted between the knee-joint kinetics of sprinting and rebound jumping (Figs. 2 & 3). Although no previous study has reported the importance of the knee joint in rebound jumping, knee-joint (knee extensor) function in drop jumping (in which ground contact time is not minimized) is crucial for regulating performance as a power source⁶ and affecting jump height due to greater energy production².

Thus, knee-joint function in rebound jumping may also affect rebound jumping performance, as with drop jumping. During the eccentric phase in sprinting, the knee joint plays an important role in regulating leg stiffness⁹ and energy absorption¹². However, in sprinting, knee extension is not necessary for achieving a high velocity, because faster sprinters show less knee extension during the support phase⁷, and knee-joint torque does not contribute substantially to power generation during the latter part of the support phase³. However, we demonstrated a significant correlation between knee-joint torque during the concentric phase in sprinting and rebound jumping, which also may explain the lack of a significant relationship between sprinting and rebound jumping performance.

Conclusion and Implication for Training

We demonstrated no similarities in performance variables, but there were mechanical similarities in ankle- and knee-joint kinetics during the support phase, especially in the eccentric phase, of sprinting and

rebound jumping. For application in plyometric training, our results indicate that plyometric training using rebound jumping may be useful for improving the mechanical output of the ankle and knee joints during sprinting. However, plyometric training using rebound jumping may increase knee extension movement via improved knee-joint mechanical output during the latter part of the support phase in sprinting, which may negatively affect sprinting performance^{3,7)}.

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